

## Description

# METHOD AND STRUCTURE FOR VERTICAL DRAM DEVICES WITH SELF-ALIGNED UPPER TRENCH SHAPING

### BACKGROUND OF INVENTION

[0001] The present invention relates generally to semiconductor structures and semiconductor device processing and, more particularly, to a method for implementing self-aligned, deep trench shaping for vertical DRAM devices.

[0002] Dynamic random access memory (DRAM) is a type of semiconductor memory in which the information is stored as data bits in capacitors on a semiconductor integrated circuit. Each bit is typically stored as an amount of electrical charge in a storage cell consisting of a capacitor and a transistor. A practical DRAM circuit usually includes an array of memory cells interconnected by rows and columns, which are generally referred to as wordlines and bitlines, respectively. Reading data from or writing data to memory cells is achieved by activating selected wordlines and bit-

lines. More specifically, a trench DRAM memory cell may include a metal-oxide-semiconductor field-effect transistor (MOSFET) connected to a deep trench (DT) capacitor. The transistor includes gate and diffusion regions that are referred to as either drain or source regions, depending on the operation of the transistor.

[0003] Typically, the deep trench capacitor is formed in a silicon substrate using one or more conventional techniques, such as reactive ion etching (RIE), with photoresist or other materials as a mask to cover the areas where trench formation is not desired. The trench is typically filled with a conductor material (most commonly n-type doped polysilicon), which serves as one plate of the capacitor, usually referred to as the "storage node". The second plate of the capacitor is typically formed by outdiffusion of an n-type doped region surrounding the lower portion of the trench, usually referred to as the "buried plate". A node dielectric layer, which may include, for example, silicon dioxide ( $\text{SiO}_2$ ), silicon nitride (SiN), silicon oxynitride (SiON), tantalum oxide ( $\text{Ta}_2\text{O}_5$ ), aluminum oxide ( $\text{Al}_2\text{O}_3$ ), or any other dielectric material, is provided to separate the storage node and buried plate, thereby forming the capacitor. The connection between the transistor and the

capacitor is achieved through the formation of what is known in the art as a "buried strap", which is commonly formed by outdiffusion of dopants from the doped polysilicon to the substrate.

[0004] Compared to a planar DRAM device, which includes a planar transfer device and a storage node in a trench, a vertical DRAM device exploits a trench to form both the storage node and the transfer device. Such vertical DRAM devices have significant advantages. For example, the memory density is increased because the length of the vertical signal transfer device channel is determined by a recess process, and therefore it is decoupled from the minimum feature size which is limited by the capability of the lithography. The vertical configuration also allows longer channel lengths without a proportional decrease in memory density. Channel length can also be properly scaled relative to gate oxide thickness and relative to junction depth to reduce channel doping, minimize junction leakage, and increase retention times.

[0005] In order to prevent carriers from traveling through the substrate between the adjacent devices (e.g., capacitors), device isolation regions are formed between adjacent semiconductor devices. Trench isolation (IT) is generally

used in the fabrication of advanced semiconductor devices. A sharply defined trench is formed in the semiconductor substrate, and the trench is thereafter filled with oxide back to the surface of the substrate to provide a device isolation region. The remaining surfaces of the substrate without IT are generally referred to as the active area (AA).

[0006] During the formation of the deep trenches, the actual resulting shape of the deep trenches is not geometrically rectangular at the upper trench portion due to the crystalline orientation dependence of the etch rate in a reactive ion etch (RIE) process. Rather, the upper portion of the etched deep trench takes on an octagonal configuration. In addition, because of process variations that occur during device processing, perfect alignment of the active areas (AA) to the deep trenches is not always achieved. As a result, the combination of a non-rectangular shaped deep trench and an AA-DT misalignment can cause a variation of the device threshold voltage ( $V_t$ ) and consequently degrades the DRAM device performance.

#### SUMMARY OF INVENTION

[0007] The foregoing discussed drawbacks and deficiencies of the prior art are overcome or alleviated by a method for

forming a memory storage cell in a semiconductor substrate. In an exemplary embodiment, the method includes forming a dopant source material over a lower portion of a deep trench formed in the substrate. An upper portion of the trench is shaped to a generally rectangular configuration, and the dopant source material is annealed so as to form a buried plate of a trench capacitor. The buried plate is self aligned to the shaped upper portion of the trench.

[0008] In another aspect, a method for forming vertical storage cell for a dynamic random access memory (DRAM) device includes forming a deep trench in a semiconductor substrate and forming a dopant source material over a lower portion of the deep trench. An upper portion of the deep trench is shaped to a generally rectangular configuration. The dopant source material is annealed so as to form a buried plate of a trench capacitor, wherein the buried plate is self aligned to the shaped upper portion of the deep trench.

[0009] In still another aspect, a semiconductor memory storage cell includes a deep trench initially formed in a semiconductor substrate. A buried plate region is formed in a lower portion of the deep trench, and an upper portion of

the deep trench is shaped to have a generally rectangular shape following the initial formation thereof, wherein the buried plate region is self aligned with the shaped upper portion of the deep trench.

#### **BRIEF DESCRIPTION OF DRAWINGS**

- [0010] Referring to the exemplary drawings wherein like elements are numbered alike in the several Figures:
- [0011] Figures 1(a) and 1(b) are schematic diagrams depicting a comparison between an unshaped deep trench and a rectangular shaped deep trench, respectively, with no misalignment between the deep trench and active area of a DRAM device;
- [0012] Figures 2(a) and 2(b) are schematic diagrams depicting a comparison between an unshaped deep trench and a rectangular shaped deep trench, respectively, with a misalignment between the deep trench and active area of a DRAM device;
- [0013] Figures 3 through 5 illustrate one possible trench shaping process utilized in the formation of a vertical DRAM cell; and
- [0014] Figures 6 through 16 are cross-sectional and top views of a self-aligned, deep trench shaping process for the upper portion of the trench, in accordance with an embodiment

of the invention.

## **DETAILED DESCRIPTION**

[0015] Disclosed herein is a shaped, upper trench structure and method for a DRAM cell that has a buried plate self-aligned to the shaped upper trench. Briefly stated, an integration scheme incorporates a process to shape the upper portion of the deep trenches to a generally rectangular shape, thereby improving the overlay of active area (AA) to deep trench (DT) in vertical gate devices.

[0016] Referring initially to Figures 1(a) and 1(b), there is shown a schematic top view illustrating comparison between an unshaped deep trench 102 and a rectangular shaped deep trench 104, respectively, with no misalignment between the deep trench and active area 106 of a DRAM device. As can be seen, the top of the unshaped trench 102 takes on an octagonal shaped resulting from the crystalline orientation dependent etch process described above. So long as there is satisfactory alignment of the active area to the deep trench, the unshaped trench 102 generally does not present a problem in terms of threshold voltage shift of the vertical DRAM device.

[0017] However, in the event of a misalignment, such as shown in Figure 2(a) for example, the active area 106 crosses the

corner of two neighboring crystal planes, as indicated by the arrow 108. This results in a disturbance in device threshold voltage and hence a degradation in device performance. On the other hand, as shown in Figure 2(b), the same alignment shift does not result in the crossing of the active area 106 over the deep trench corner if the upper portion of the deep trench is shaped in a generally rectangular fashion.

[0018] Accordingly, deep trench shaping (i.e., a process to shape the octagonal upper portion of trenches so as to make them rectangular) has been developed to address this problem. Initially, this shaping was tested at the final stages of the deep trench/DRAM cell formation process, as shown in Figures 3 through 5. In particular, Figure 3 illustrates the formation of a trench top oxide material 120 atop a completed trench capacitor, designated generally at 122. (It will be noted that the buried plate portion of the capacitor is not illustrated in Figures 3–5.) As shown in the top-down, cross-sectional slice in the lower portion of Figure 3, the trench top oxide 120 is formed prior to any shaping of the octagonal upper portion of the trench 124. Figure 4 illustrates the widening of the upper part of the trench 124 to a generally rectangular shape with an



ammonia wet etch, followed by the formation of the gate dielectric 126 (such as an oxide) as shown in Figure 5.

[0019] Unfortunately, one problem discovered with this DT upper shaping approach is that the neighboring trenches could merge together as trenches have become more significantly widened during prior processing steps. These merging trenches can then cause film peeling on the wafers, which in turn results in severe contamination issues. In addition, the shaping of the upper trench after formation of the trench top material 120 degrades the reliability of the vertical gate dielectric 126 due to the irregularity of the corner between the trench top material 120 and the gate dielectric 126, as indicated by the arrow 128. Thus, it would be desirable to be able to implement a trench shaping process that improves the AA-DT overlay tolerance for vertical array devices without causing trench merging and/or gate dielectric reliability degradation.

[0020] Therefore, in accordance with an embodiment of the invention, Figures 6–16 illustrate an exemplary process sequence that may be used to create a vertical DRAM cell wherein the upper portion of the deep trench thereof is shaped in a manner such that the upper portion of the trench is aligned with the buried plate formed by outdif-

fusion at the lower portion of the trench. The trench shaping is performed before the formation of the trench top material.

[0021] As shown in Figure 6, the starting material is a semiconductor substrate 200 having a pad layer 202 (e.g., nitride) formed atop an optional oxide layer 204. The substrate 200 may be any suitable semiconductor material, such as silicon (Si), germanium (Ge), SiGe, silicon-on-insulator (SOI), gallium arsenide (GaAs), gallium phosphide (GaP), etc. The thickness of the pad oxide layer 204 may be from about 1 nanometer (nm) to about 20 nm, while the thickness of the pad nitride layer 202 may be from about 20 nm to about 500 nm.

[0022] Figure 7 illustrates the formation of a deep trench 206 through the pad layers 202, 204 and into the substrate 200 in accordance with conventional trench formation techniques known. The depth of the trench 206 may be from about 1 micron ( $\mu\text{m}$ ) to about 15  $\mu\text{m}$ , for example. It will be noted from the top view portion of Figure 7 that the shape of the upper part of the trench 206 is octagonal. In addition, for purposes of clarity, the top down view portions of the Figures illustrate the view in cross section, and therefore do not illustrate any material present at the

very bottom of the trench 206.

[0023] Then, as shown in Figure 8, a dopant source material 208 is deposited on the trench sidewalls, and is used to provide the dopant material for diffusion into the substrate during the buried plate formation of the trench capacitor. The dopant source material may be any suitable material containing dopants such as arsenic (As), phosphorous (P), antimony (Sb) for n-type buried plate, or, in the event a p-type buried plate is desired, boron (B). However, a preferred dopant material is arsenic-doped silicate glass (ASG). The dopant source material may be deposited by a chemical vapor deposition (CVD) process, such as low pressure chemical vapor deposition (LPCVD), and plasma enhanced chemical vapor deposition (PECVD), etc. In the exemplary embodiment described hereinafter, ASG is used as the dopant source material. The thickness of ASG layer 208 may be, for example, about 5 nm to about 100 nm, depending on the trench size.

[0024] Once the ASG layer 208 is formed on the trench sidewalls, the trench 206 is filled with photoresist 210, which is thereafter recessed to a predepth as shown in Figure 9. The recessed photoresist 210 serves as an etch stop layer during the next process step such that the ASG layer 208

is removed from the upper portion of the deep trench 206 while remaining in the lower portion of the trench 206 for the buried plate formation. The photoresist recess step may be accomplished by a chemical dry etching (CDE) process, for example. As shown in Figure 10, the ASG layer 208 in the upper portion of the trench 206 is stripped while ASG in the lower portion of the trench 206 is protected by the photoresist 210. The removal of the ASG material may be achieved by buffered hydrofluoric (BHF) etch, or a diluted hydrofluoric (DHF) etch. Thereafter, the remaining photoresist in the lower trench is then stripped by a wet process, such as sulfuric acid/hydrogen peroxide ( $\text{H}_2\text{SO}_4/\text{H}_2\text{O}_2$ ), or by dry process such as CDE or ashing. As a result, only the lower portion of the trench 206 is covered by the ASG layer 208.

[0025] Referring now to Figure 11, the shaping of the upper portion of the trench 206 is illustrated. Through the use of an ammonia wet etch, the octagonal trench surfaces are shaped to a generally rectangular configuration due to the fact that ammonia etches silicon at different rates on different crystalline planes. Moreover, because the lower trench surfaces are protected by the ASG layer 208, there is no shaping therein. Because the upper trench surfaces

are shaped at this particular point in the process, they will be self-aligned to the buried plate. Other etch processes that have different etch rate at different crystalline orientations may be used for trench shaping, such as a KOH etch or plasma etch, for example. Then, as shown in Figure 12, a cap layer 212 is optionally formed over the entire trench sidewall to seal the ASG layer 208. The cap layer 212 may include undoped oxide, polysilicon, nitride material, for example. The cap layer may be formed by known CVD process.

[0026] A thermal anneal to drive the dopant into the substrate so as to form the buried plate 214 that is self-aligned to the shaped upper trench is shown in Figure 13. Preferably, the wafer is thermally annealed at a temperature of about 800 °C to about 1200 °C for about 1 to about 60 minutes, more preferably at about 1050 °C, for about 3 minutes. The annealing environment may contain oxygen, nitrogen, hydrogen, argon, or any combination thereof. If oxygen is present, the sidewall of the lower trench covered by ASG will be oxidized to form an oxide layer (not shown). Then, both the cap layer 212 and the ASG layer 208 are stripped by BHF or DHF as shown in Figure 14. If the annealing is performed in the environment containing oxygen, the

formed oxide layer described above is stripped along with ASG and cap layers to form a bottle-shape (not shown) in the lower portion of trench (bottle is not shown). The formed bottle-shape is also aligned to the shaped upper portion of the trench.

[0027] At this point, the cell is prepared for the remaining steps in the formation of a vertical DRAM device, shown in Figure 15, including the deposition of a node dielectric material 216 (e.g.,  $\text{Si}_3\text{N}_4$ , SiON,  $\text{SiO}_2$ , or other high dielectric constant materials), and a node conductor material 218 (e.g., doped polysilicon) to complete the formation of the trench capacitor. The vertical device also includes a collar 220 (e.g., an oxide) to isolate the access transistor in the upper trench from the trench capacitor in the lower trench. A trench top insulating material 222 (e.g., an oxide) isolates the gate conductor 224 from the node conductor 218. A gate dielectric 226 (e.g., an oxide) is formed on the upper trench sidewalls for the vertical transistor. In addition, a buried strap 228 electrically bridges the node conductor to outdiffusion 230 of the access transistor. Further information regarding the formation of vertical transistors may be found in U.S. Patent Nos. 6,414,347 and 6,440,793, assigned to the assignee of the

present application, the contents of which are incorporated herein by reference.

[0028] Finally, Figure 16 illustrates the formation of isolation trenches 232 for electrical isolation of the neighboring cells/devices, wherein the trenches are etched and then filled with an insulating material such as an oxide.

[0029] It will thus be appreciated that even when a misalignment of the device active area to the deep trench, the active area will still only cross one orientation of the substrate crystalline planes as a result of the shaped, square upper portion of the trench. In addition, it is also contemplated that the above described disclosure contemplates any scheme that shapes the upper trench without shaping the lower trench. For example, the ASG may be replaced by any other materials such as nitride, SiC, SiGe, or undoped oxide to cover the lower trench by resist recess. In other words, the material used to shield the lower portion of the trench from shaping is not necessarily also to be the dopant source material used to form the buried plate.

[0030] As compared with the post trench top oxide shaping approach shown in Figures 3-5, the present scheme has several advantages. First, the shaping of the upper portion of the deep trenches is performed at the early stage of

device fabrication, so trenches are less susceptible to the problem of merging. Second, because the lower portions of the trench are covered by ASG, only the upper portion gets shaped during the wet etch. Thus, if there are any defects in the lower portion of the trench, such as side pockets for example, they will not be aggravated by the above process. Finally, any ASG residue on the sidewall of the upper trench will be lifted off during shaping, thereby suppressing any undesired arsenic doping in the upper trench.

[0031] While the invention has been described with reference to a preferred embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.



[0032] What is claimed is: